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Editorial

Visual control of mobile robots

1. Introduction

The autonomous navigation of mobile robots is a key problem in the robotics community that has attracted enormous research efforts for many years. Steady progress has been made in this area and, in recent years, we are witnessing the impressive development of totally autonomous vehicles able to drive in real environments. This is a qualitative advance that undoubtedly will produce a tremendous impact in our daily life. The interest in systems capable of performing efficient and robust autonomous navigation lies in the many potential applications in industrial as well as domestic settings. Among the variety of sensors available today, vision systems stand out because they provide very rich information at a low cost. Thus, the common denominator of any flexible and versatile autonomous navigation system is the integration of vision in the control loop. However, the versatility of vision systems comes at the cost of higher data processing complexity.

Visual control or visual servoing has been one of the major research issues in robotics for more than four decades. In general terms, the basic idea of visual servoing is to stabilize the position of a robot to a desired location by regulating to zero an error term which is estimated using information extracted from images (current and target). This idea, also called *homing*, is similar to the ability of insects such as bees, ants, and wasps to return to specific places by storing a snapshot at the target location and later estimating the direction to it from their current position. In the framework of visual control, the methods are generally classified as *image-based*, if the image data is used directly in the control loop, *position-based*, if the image data is used to compute pose parameters, and *hybrid* or *partitioned*, if a combination of the two previous types is used. However, this classification no longer captures the diversity and particularities of the different strategies that have been investigated in the visual control literature. In this context, venues such as workshops or journal special issues are necessary in order to extend the state of the art on this topic.

Within the framework of autonomous navigation, the integration of vision in the control loop is still an open and ambitious research area. Besides, visual control is a multidisciplinary field of research that requires the collaboration of the computer vision and robot control communities. However, there is still a gap between these communities that hinders the achievement of more profitable results from joint research. Thus, one of the goals of this Special Issue is to bring together research works that fill this gap, presenting the latest advances in the field and disseminating their results to the scientific community.

2. The ViCoMoR workshop

This Special Issue on Visual Control of Mobile Robots (ViCoMoR) stems from two workshops that were organized in conjunction with the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). The purpose of these workshops was to discuss topics related to the challenging problems of visual control of mobile robots. They were useful to enhance active collaboration of researchers, discuss formal methods for visual control and identify current trends in the field. The first edition of the ViCoMoR workshop was held in San Francisco (USA) in September 26^{th}, 2011, and the second one took place in Vilamoura (Portugal) in October 11^{th}, 2012. The workshops were opened to paper submissions, which were reviewed by the workshop Program Committee. The acceptance rates in ViCoMoR 2011 and 2012 were 55% and 66% with 8 and 10 presentations scheduled, respectively. The technical programs included keynote speakers that shared their experience and gave an insight into the evolution and current status of visual control, namely François Chaumette, Nicholas R. Gans, Patrick Rives, and Cédric Pradalier. The workshops attracted the interest of the public and each of them was attended by more than 30 people. More details about these workshops can be found at http://vicomor.unizar.es.

3. Summary of the special issue

Due to the interest in the topic of visual control and the success of the workshops, we promoted this Special Issue, which was open not only to papers presented at ViCoMoR workshops but also to contributions not previously published. This special issue collects the 5 best papers selected among the 12 papers submitted. We believe that they are nice examples that cover relevant topics within the field of vision-based control. A brief introduction to these papers follows.

A relevant issue in vision-based navigation is the field-of-view constraint of conventional cameras, due to which image features are not guaranteed to remain in the camera's field of view. Omnidirectional cameras are an excellent means to overcome this issue in an effective way by providing a panoramic view from a single image. However, omnidirectional cameras are more difficult to model as they are in general non-central systems for which a single viewpoint cannot be assumed. The paper by Aliakbarpour et al. considers the radial projection model and presents a control scheme for mobile robots valid for a wide class of catadioptric cameras including non-central systems consisting of an axially symmetric mirror and a perspective camera. New visual features are defined in accordance with the radial model and then, an image-based control is proposed exploiting the decoupling properties of the visual features. The simulations and real experiments provided using different catadioptric systems demonstrate the feasibility and effectiveness of the proposed method.

Instead of using image features directly in the control loop, multiple view geometry models such as homography or epipolar geometry have been employed to tackle the problem of visual control. Imposing multiple view geometric constraints results in improved performance and robustness, but also often leads to degenerate cases or singularities in the control law. The work by Becerra et al. proposes taking advantage of three-view geometry to design a control scheme able to regulate the mobile robot to the target location avoiding local minima. The authors present a new formulation of the control problem based on the trifocal tensor where a virtual target is defined in the control task so as to avoid degeneracies of the model. Moreover, in order to guarantee continuous control inputs and robustness against perturbations, a super-twisting control scheme is introduced. Stability proof of the closed loop system under the control proposed is also provided.

The necessity to extract and match or, alternatively, track image features is a well known bottleneck in classical visual control methods. This is a complex and error-prone process involving computationally expensive algorithms, which limits the expansion of visual control techniques. The paper by Silveira investigates a visual servoing technique that directly exploits the pixel intensities avoiding any feature extraction or matching algorithm. This intensity-based scheme works at the level of raw and dense image data, improving efficiency and robustness and providing higher accuracy. In this framework, a new position-based visual servoing method is proposed. The method is evaluated with a robotic arm, a classical platform in visual servoing research that many times led to successful adaptations to other platforms, such as nonholonomic mobile robots.

In recent years, there has been an increasing interest in micro aerial vehicles within the robotics community. The interest in these platforms resides in their wide range of applications and versatility. However, they are more complicated to control than robots constrained to planar motion, raising new challenges still under research both in the control and perception aspects. Here, visual perception is a key issue given that cameras provide very rich information at a low weight, power consumption, and size, which are main aspects to be considered in the design of aerial vehicles. The paper by Engel et al. presents a complete vision-based navigation system using an on-board camera to navigate a low-cost quadcopter in an unknown, unstructured environment. Extensive and impressive experiments support the proposal. Additionally, the authors provide the source code of the complete system available to the community as open source software.

In the paper by Ta et al., the robotic platforms considered are also micro aerial vehicles. The authors address the indoors perception problem in feature-poor environments as well as the lack of motion parallax, needed to triangulate new landmarks in the scene, when the camera purely rotates. The contribution of this vision-based navigation system is sustained by two different kinds of features. On the one hand, the authors consider what they call *vistas*, a kind of distant feature derived from scale-space properties and used for steering the quadcopter toward open spaces. On the other hand, they present a low dimensional *Wall-Floor Feature*, based on the intersection of vertical lines with the floor, designed to cope with feature-poor environments and infer the structure of the scene. This approach is introduced in a parallel tracking and mapping framework with odometry that results in successful autonomous flying.

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